FORECAST PROBLEMS DURING THE LIFE CYCLE OF A CUT-OFF L W, JANUARY 20–29, 1962

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ABSTRACT

The life cycle of a cut-off Low at the 500-mb. level in the southwestern United States, January 20–29, 1962, is examined. The forecast problem is analyzed with the numerical barotropic predictions used as the first approximation. The effects of the mountains on the forecasts are discussed. The relative success of modifications to the barotropic forecasts, along with reasons for these modifications, is shown. Some aspects of the surface developments with respect to events at the 500-mb. level are examined.

1. INTRODUCTION

The 500-mb. cut-off Low in the southwestern United States presents a challenge to the forecaster. First he must recognize the mechanisms which result in the formation of the cut-off Low. Once the Low is cut off, he must decide whether it will progress or retrogress. When retrogression occurs, the forecaster must decide to what extent this will take place. Following retrogression, the Low is almost invariably quasi-stationary for a period. Finally the forecaster must determine at what time the Low will commence to move eastward. In addition, he must relate all this to surface developments and their associated weather patterns.

This article deals with the life cycle of the southwestern cut-off Low of January 20–29, 1962, divided into Phase I, covering the period of the formation and the retrogression of the cut-off Low; Phase II, the eastward movement of the Low beginning at 1200 GMT on the 24th, and Phase III, commencing at 1200 GMT, on the 27th, the final development influencing United States weather, as the Low moved across the Atlantic coast.

Emphasis is on events at the 500-mb. level. More specifically, an attempt is made to compare the forecasts of these events by barotropic prognoses computed by the Numerical Weather Prediction Unit (NWP) with the modified forecasts prepared by the Analysis and Forecast Branch (A&FB), both of the National Meteorological Center. The approach is diagnostic in nature with an effort to highlight some of the difficulties in the forecast problem. The charts shown in the illustrations are copies of the operational charts used in the National Meteorological Center.

2. THE CUTTING-OFF OF THE LOW AND ITS RETROGRESSION

On January 20, 1962, at 0000 GMT, a surface storm in the process of intense cyclogenesis was moving inland near the Oregon-California border (fig. 1A). The 500-mb. chart for the same time is shown in figure 1B. The observed track of the 500-mb. impulse is shown in figure 2 along with the NWP forecast track and the A&FB track resulting from modification to the NWP forecasts. It can be seen that, early in the period, NWP erroneously predicted the center to be too far east. It was not until the 500-mb. Low was cut off and had commenced to retrograde that the NWP forecast and observed positions became nearly coincident off the southern California coast on the 23d. The A&FB modifications, resulting in an even more easterly track than that of the NWP forecasts, were unsuccessful during this phase.

Initially, when the surface storm was intensifying, the A&FB forecasters were too impressed with the apparent baroclinicity of the surface development to recognize fully the possibility of a cut-off Low forming aloft; they treated the system as a vigorous moving short wave. The normal baroclinic correction was applied to the NWP forecasts. This correction rotated the trough in an anticlockwise direction south of the center of maximum vorticity, with the greatest correction applied in the vicinity of the thermal jet [7]. Aside from the barotropic indications, the most obvious clue to the situation that was missed by the A&FB forecasters was the advection of anticyclonic vorticity into the eastern Pacific (fig. 3A) resulting in a strong blocking ridge. This contributed to the stabilization of the long-wave trough position on the west coast of the United States. Even after this Low was recognized as cut off, the A&FB forecasters were confounded by the fact that errors in the barotropic forecasts did not conform to earlier observed error patterns. The systematic errors observed with previous cut-off Lows indicated a tendency for the barotropically forecasted center to retrograde too far westward [3, 4].

It is recognized by A&FB forecasters that the mountains exert a considerable influence on the behavior of weather

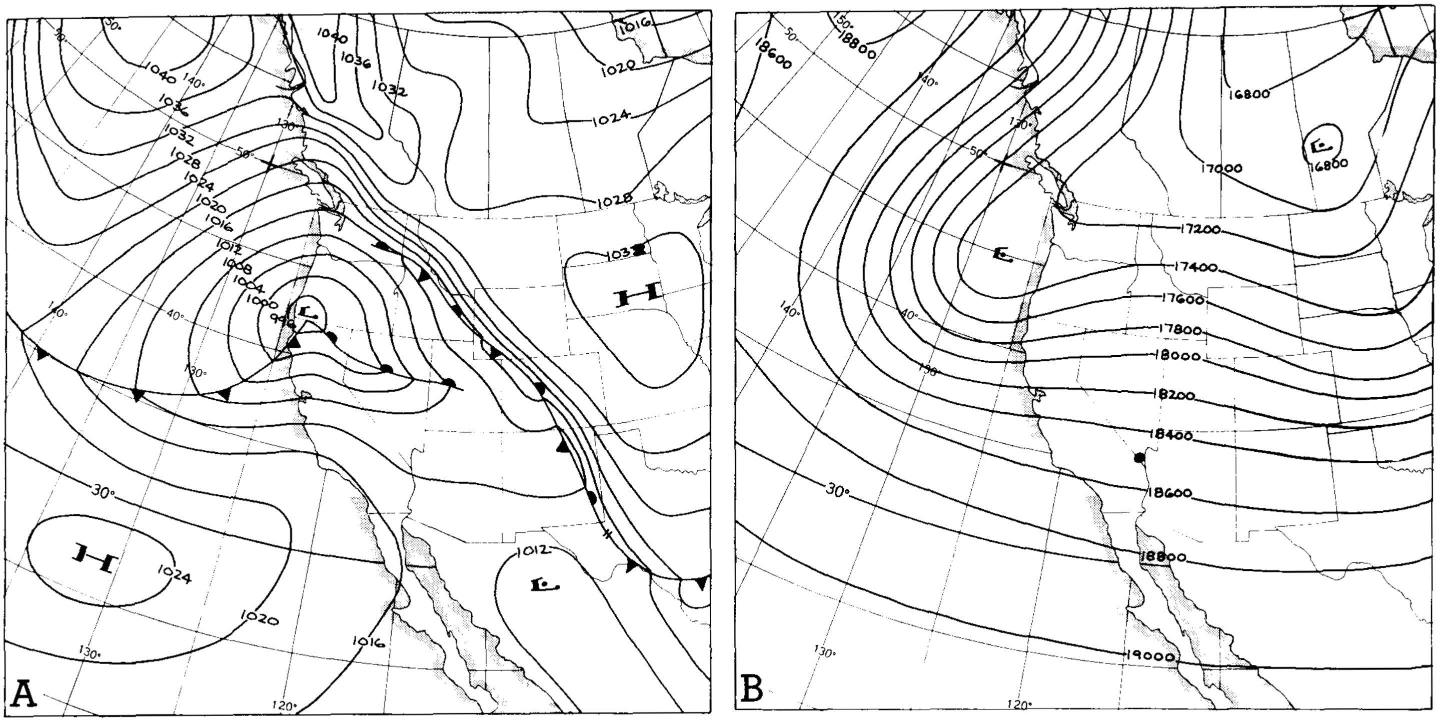


FIGURE 1.—(A) Surface and (B) 500-mb. charts for 0000 GMT, January 20, 1962.

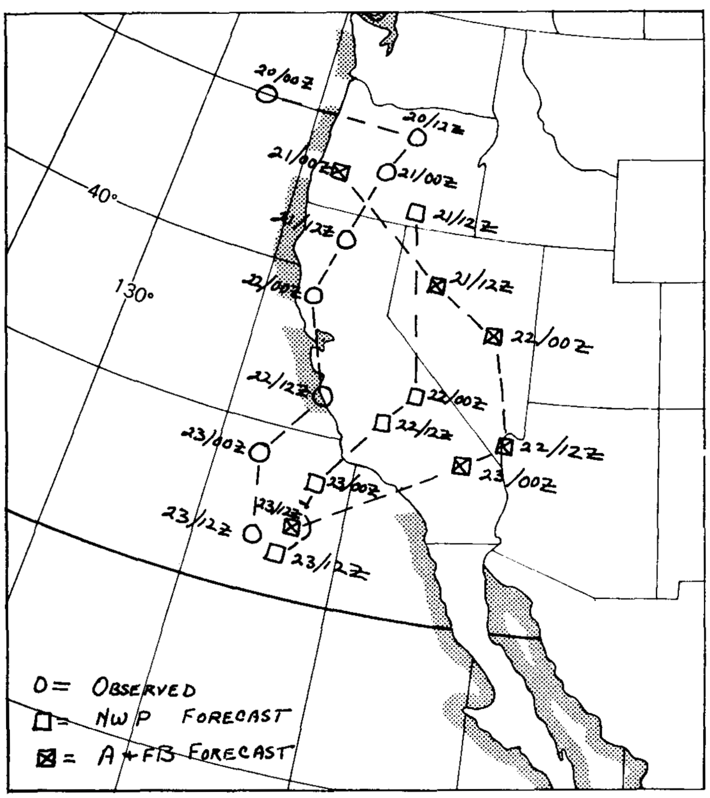
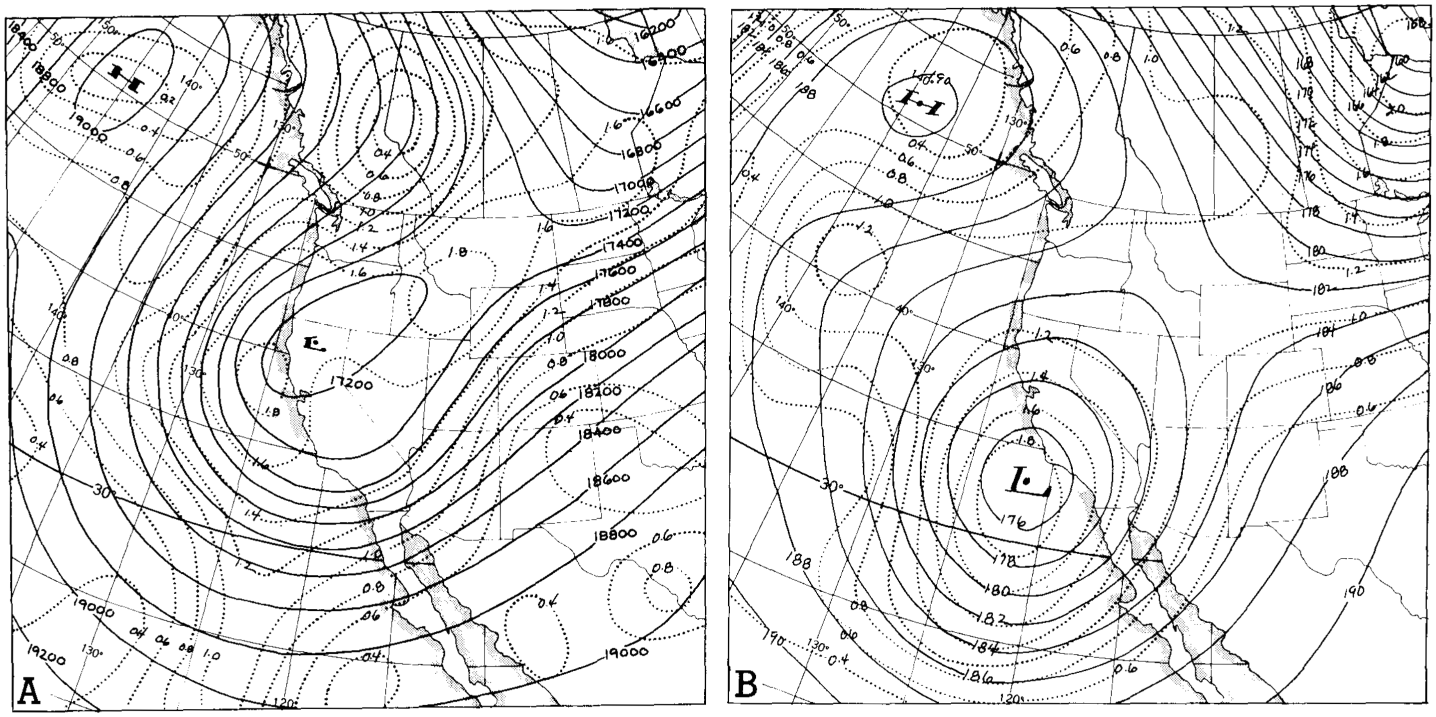


FIGURE 2.—500-mb. Low track (observed and forecast) for Phase 1, January 20–23, 1962. Observed track represented by ○, NWP 36-hour forecast track by □, and A&FB forecast track by ⊠.

patterns in western North America. The barotropic model presently in use contains a correction factor for friction and the mountain effects [1]. Although tests by Cressman indicate that the correction produces a considerable overall improvement in the barotropic forecasts for the mountainous regions of western North America, there is some evidence to support the belief that this problem has not been completely solved. Some results of an investigation by Fawcett [4] and Gustafson of errors associated with the inclusion of the mountain correction term in the barotropic model are expected to appear as a supplement to [3]. The estimating equation used to derive surface winds from 500-mb. winds [1] often gives erroneously strong surface winds in the case of cut-off Lows. The resulting overforecast of the flow up the west slopes of the mountains creates too much anticyclonic vorticity in the mountainous region. Therefore, forecast heights are too high over the mountains and a ridge is forecasted to retard the movement of short waves eastward.

It has been seen that in the early stages of this situation, before the 500-mb. center was well cut off, the barotropic model forecast the center too far to the east. However, the reason for the error here was probably due to the tendency of the barotropic model [3] to be slow in predicting the cutting-off process rather than to an erroneous mountain correction. At this time, winds normal to the mountains were strong (fig. 1B). When the 500-mb.



Low became cut off and commenced to retrograde, the strongest winds around the Low moved westward off the coast (fig. 3A). It was then that most of the errors in the NWP forecasts disappeared.

The NWP 36-hour 500-mb. prognosis, based on the 1200 GMT data on the 21st, was a remarkably successful forecast. Contributing to the success of this forecast was the excellent input data supplied by reconnaissance flight reports in the eastern Pacific. The 500-mb. chart for 1200 GMT on the 21st, with the vorticity analysis superimposed, is shown in figure 3A. It can be seen that the jet coming out of the Pacific Northwest is well defined on the upstream side of the trough, while the winds over most of the mountainous West are relatively weak and have become more nearly parallel to the mountains. The forecast chart for 0000 GMT on the 23d with its vorticity field is shown in figure 3B. The verification of this forecast can be seen in figure 3C. It can be readily observed how successful the barotropic forecast was in predicting the extent to which the Low would be cut off, along with its retrogression. The NWP forecast based on data 12 hours later was equally successful. Indeed, with this forecast, the observed 500-mb. center and the forecast center were nearly coincident for 1200 GMT on the 23d. During the course of the previously mentioned investigation by Fawcett [4], a test forecast omitting the friction and mountain terms from the NWP model was computed for the verifying time 1200 GMT on the 23d. The result of this run was worse than the regular NWP prognosis. The 500-mb. center was forecast to remain onshore in southern California. This would tend to support the idea that with 500-mb. Lows that are already cut off at initial time, and in the absence of strong wind fields impinging on the mountains, the barotropic model presently in use has the capability of accurately predicting the movement of these Lows in the west coast region as long as they are not moving eastward.

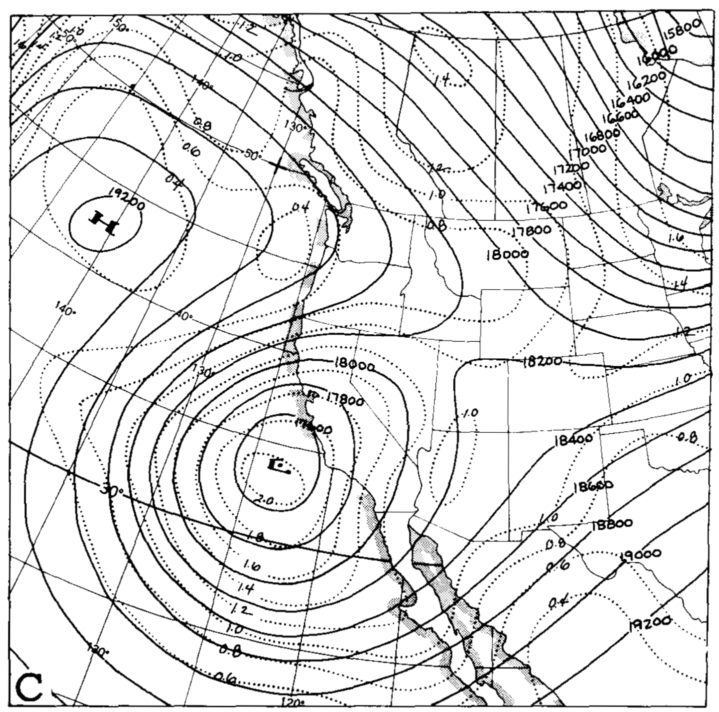


Figure 3.—500-mb. height contours (solid lines in hundreds of feet) with absolute vorticity analysis (dotted lines with units of 10^{-4} sec.$^{-1}$). (A) Initial analysis for 1200 GMT, January 21, 1962, (B) NWP 36-hour forecast, verifying time 0000 GMT, January 23, 1962. (C) Verification analysis, 0000 GMT, January 23, 1962.

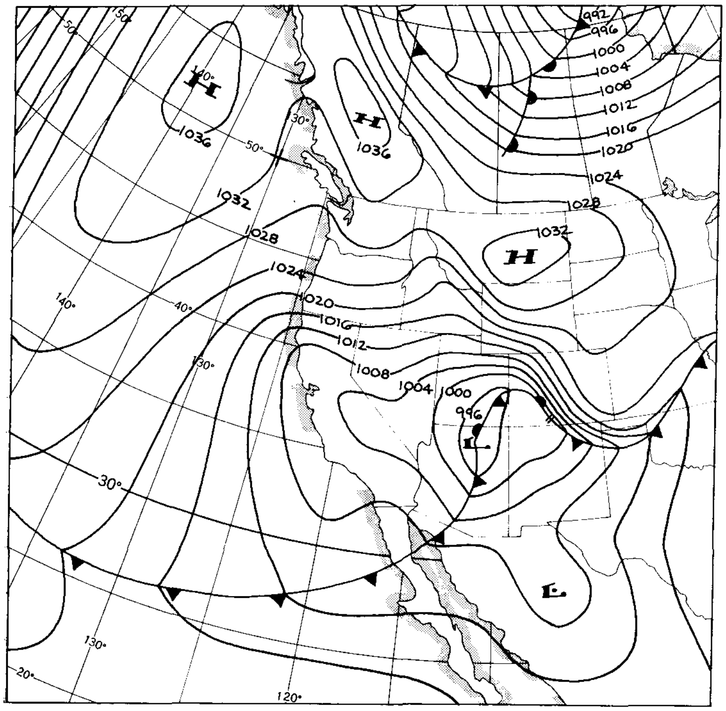


FIGURE 4.—Surface analysis for 1200 GMT, January 21, 1962.

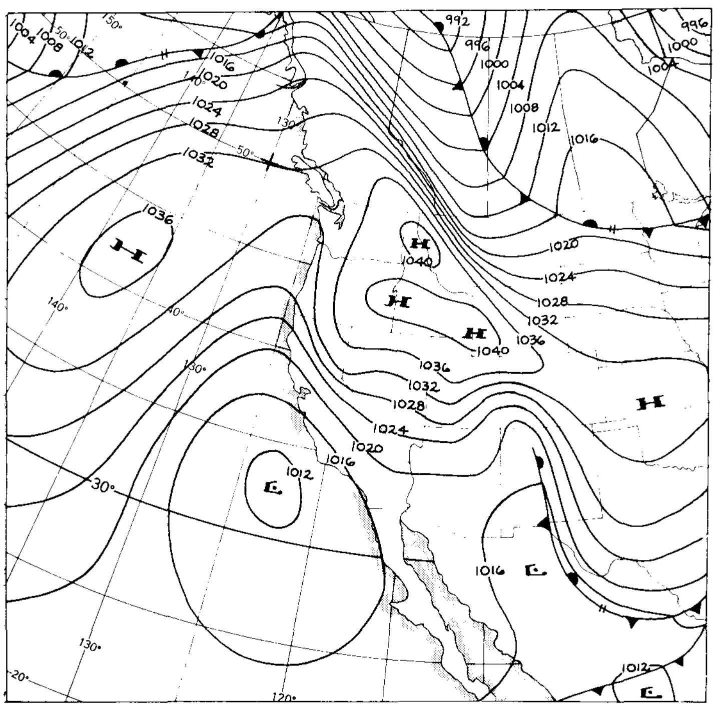


FIGURE 5.—Surface analysis for 0000 GMT, January 23, 1962.

It is interesting to reflect a bit on what transpired at the surface during the period in which these events were taking place aloft. As has already been noted, the Low was developing rapidly as it was moving inland early on the 20th. It reached maximum intensity between 0600 and 1200 GMT on the 20th with a minimum surface pressure of 982 mb. During the next 24 hours the Low moved east-southeastward, remaining quite vigorous, so that by 1200 GMT on the 21st (fig. 4) it was centered north of Winslow, Ariz., with a minimum surface pressure of 994 mb. As the 500-mb. jet progressed down the Pacific Northwest coast, accompanied by rising heights in the Northwestern States, large surface pressure rises occurred in this region. This served to intensify the easterly surface flow from the Continental Divide to the Pacific coast. These strong easterlies, transporting cold air from the Great Basin, resulted in the unusual occurrence of snow along the coastal region and in the valleys of California as far south as Los Angeles.

As the 500-mb. Low became more and more cut off and retrogressed southwestward, the surface system progressively lost its intensity. Rapid filling started around 1200 GMT on the 21st and continued for the next 36 hours. By 0000 GMT on the 23d (fig. 5), little more than a weak inverted trough through central New Mexico remained. Meanwhile, a well developed surface cyclonic circulation appeared off the coast of southern California beneath the Low aloft.

3. THE CUT-OFF LOW MOVES EASTWARD

By 1200 GMT on the 23d, the 500-mb. center had moved southward to 32° N., 123° W., and at this point its course changed abruptly to an eastward direction. Although the barotropic 500-mb. forecasts had correctly predicted this change in direction, they did not show enough eastward progression, and as late as 1200 GMT on the 24th the barotropic 36-hour forecast continued to keep the center offshore (fig. 7A). As discussed in section 2, in connection with the study by Fawcett [4], this deficiency may be partially due to the excessive influence of the mountain term [1] in the barotropic forecast model; i.e., until the closed Low crosses the Continental Divide (or until the southern half of its circulation is predominantly downslope rather than upslope), its eastward or northeastward emergence will be "blocked" in the forecasts by the prediction of too much ridging over the mountains.

It had been recognized at A&FB that the prognosis would probably be susceptible to this characteristic error, previously described by Dunn [3], consequently other clues as to the timing of this event were sought. By 1200 GMT on the 24th, cloudiness and precipitation were increasing once more in the Southwestern States. The 12-hour surface pressure-change chart showed falls of more than 4 mb. in southern California and southern Arizona with a corresponding rise of over 4 mb. west of Guadeloupe. Height at 500 mb. in the vicinity of Ship "P" had been steadily decreasing, with indications that this strengthening of the westerlies to the rear of the cut-off Low would continue. The Low itself had continued an eastward movement of 3° of longitude every

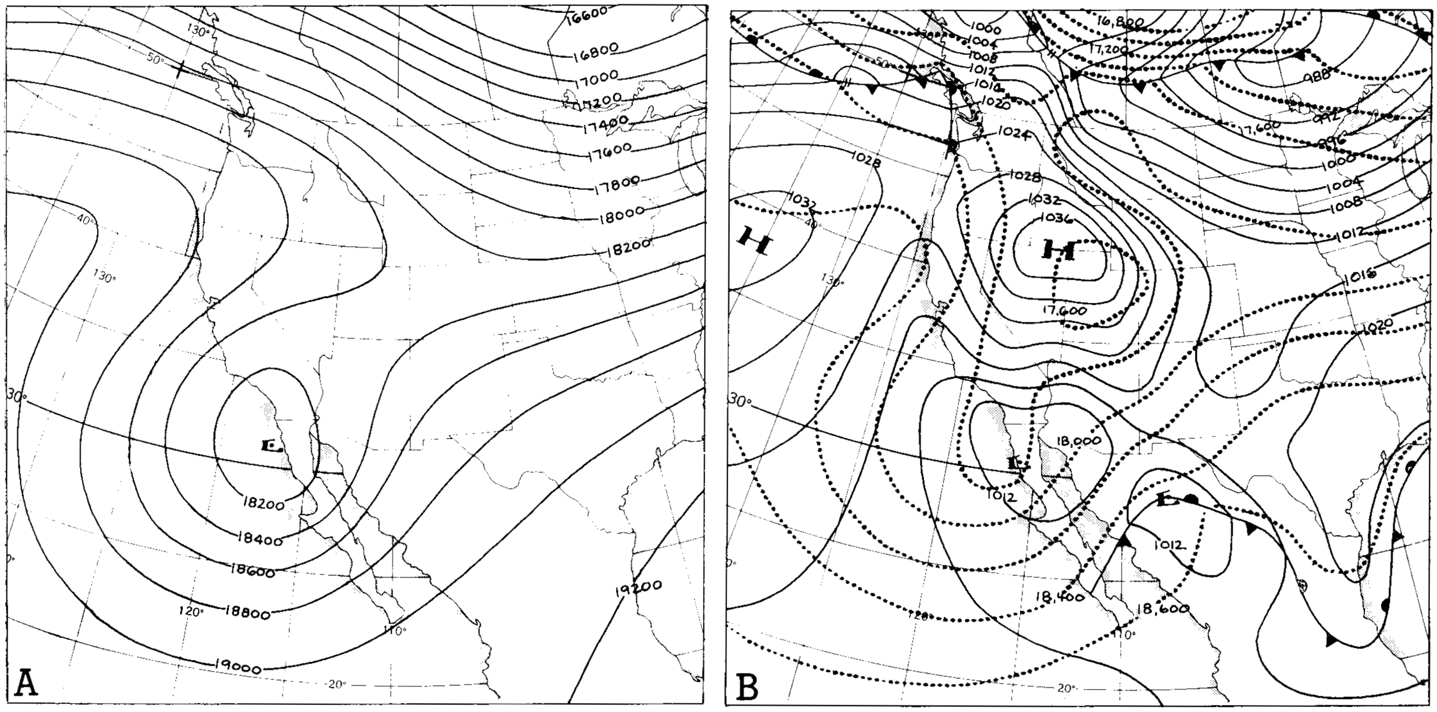


Figure 6.—(A) 500-mb. contour analysis, 1200 GMT, January 24, 1962. (B) Surface (solid lines) and 1000–500-mb. thickness (dotted lines) analyses, 1200 GMT, January 24, 1962.

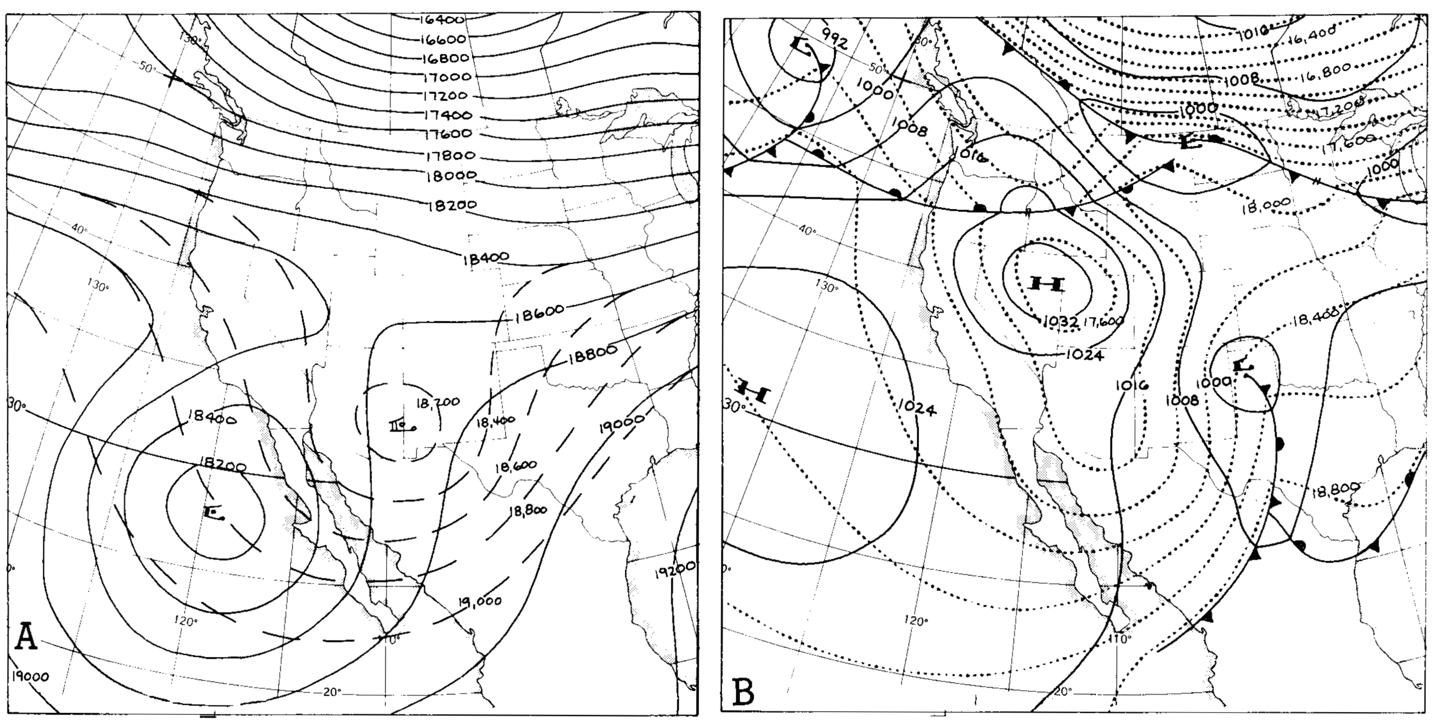


Figure 7.—(A) NWP 36-hour barotropic 500-mb. contour forecast (solid lines) and A&FB modification (dashed lines), verifying time 0000 GMT, January 26, 1962. (B) A&FB 36-hour surface forecast (solid lines) and 1000–500-mb. thickness forecast (dotted lines), verifying time 0000 GMT, January 26, 1962.

12 hours and was located just off the Lower California coast (fig. 6A). Surface development inland appeared to be imminent.

Since the barotopic forecast was considered unreliable in this particular case, the accompanying vorticity charts were also disregarded. The first problem, then, was estimating a location for the 500-mb. center at a 36-hour verifying time of 0000 GMT on the 26th. Extrapolation

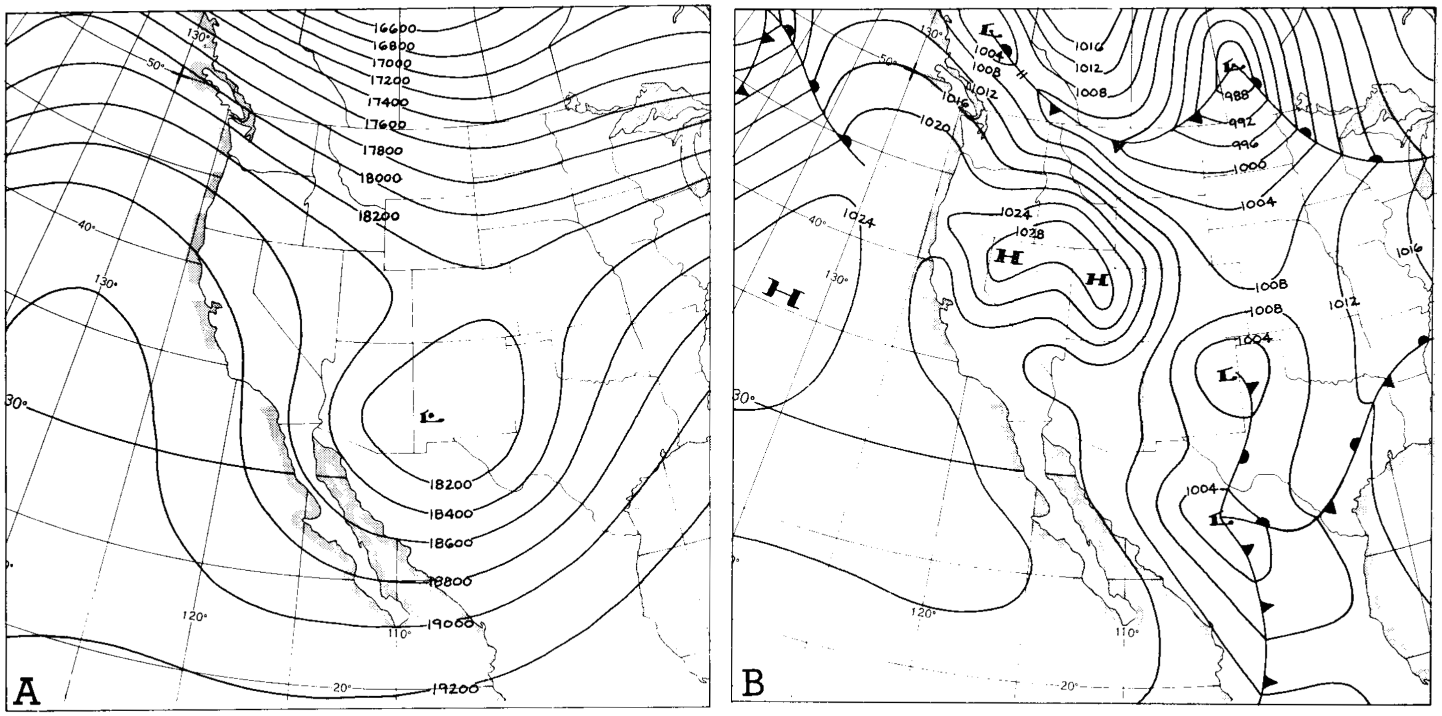


FIGURE 8.—(A) 500-mb. contour analysis, 0000 GMT, January 26, 1962. (B) Surface analysis, 0000 GMT, January 26, 1962.

of previous motion indicated a position about 9° farther east (at the longitude of western New Mexico) after 36 hours. A Wilson Grid computation [14] gave an eastward movement ot about 6° in that time, a forecast which was

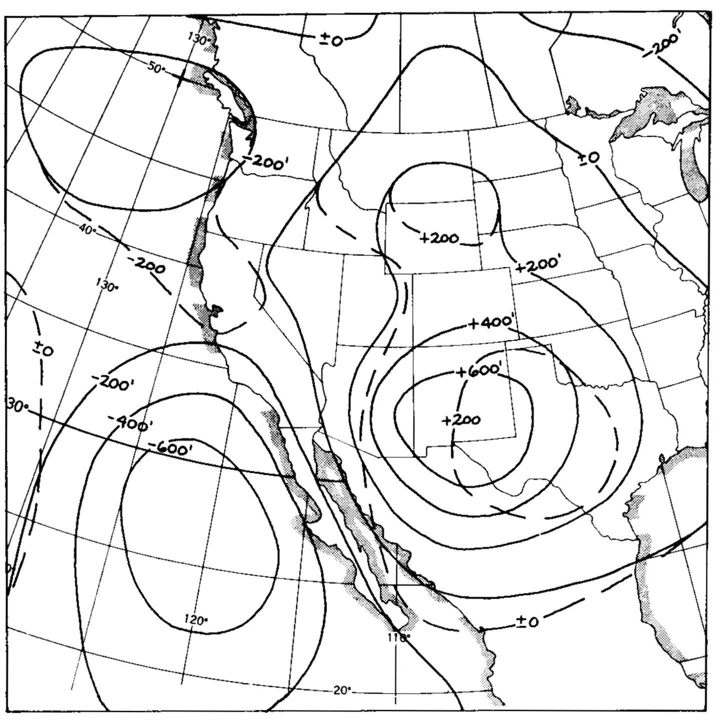


FIGURE 9.—Error of the NWP 36-hour barotropic 500-mb. contour forecast (solid lines) and A&FB modification (dashed lines) verifying at 0000 GMT, January 26, 1962.

thought to be slow in view of the expected surface development and consequent baroclinicity of the system. In any event, it did not appear that the closed Low would be "picked up" by a passing short-wave trough from the northwest, and therefore appreciable acceleration was thought to be unlikely. As a first approximation, the center was placed at the longitude of the Arizona-New Mexico border, with the exact latitude to depend on the location of the forecast surface Low.

The initial 1000–500-mb. thickness analysis (fig. 6B) showed a zone of strong thermal gradient extending from New Mexico through northern Texas into Oklahoma, with the axis of the thickness ridge through Oklahoma. With the 500-mb. Low expected to move toward this area, positive vorticity would be approaching the thickness ridge and the most likely place for cyclogenesis, according to A&FB practices [7] based on Sutcliffe's articles on development [11] [12], would be a spot on the thermal jet lying about ¾ of the distance from the thickness trough to the downstream ridge. This location (near Amarillo, Tex.) was also within an area Petterssen [9] showed to be climatologically favorable for development, and the surface center was placed accordingly (fig. 7B). At this time the 500-mb. Low (left previously on the Arizona-New Mexico border) was located at 33° N., which would show the upper Low following the surface center and also give a slope between these systems consistent with the study by Wiin-Nielsen [13].

The initial thickness (fig. 6B) indicated the strongest thermal gradient lying well to the north of the area in question; thus the strong cold air advection needed for pronounced surface deepening in Texas was not likely to occur. A central pressure of 996 mb. representing only moderate intensification, was forecast.

The final problem was to determine the central height of the predicted 500-mb. Low. First, a subjective thickness forecast was prepared (fig. 7B), using the features of the surface prognosis as a guide and keeping in mind that the forecast should follow logically from the initial conditions. The result was graphically added to the 1000-mb. forecast, which gave a closed 18,200-ft. contour around the 500-mb. center (fig. 7A); this appeared reasonable in view of the initial depth at that level.

The A&FB prognoses were successful in the area under discussion. The 500-mb. center was accurately forecast as to depth and location (fig. 8A), while the height-error pattern of the modified prognosis showed a marked improvement over that of the unmodified barotropic forecast (fig. 9). The surface Low verified within 100 mi. and 4 mb. of the forecast position and intensity (fig. 8B). Thus, recognition of a situation where the barotropic forecast required considerable modification led to a vastly better surface prognosis than would otherwise have been produced, a prerequisite for improved forecasts of weather conditions at the local level.

4. 500-MB. ACCELERATION AND ASSOCIATED SURFACE INTENSIFICATION

Between 1200 GMT on the 25th and 1200 GMT on the 27th, the 500-mb. Low moved eastward at the steady speed of about 4° of longitude every 12 hours to a position near Shreveport, La. (fig. 10A). During this period, A&FB consistently and successfully modified the NWP forecasts to indicate greater eastward displacement of the 500-mb. trough. These modifications were not due to any marked indication of baroclinicity but rather to the characteristic slowness in the barotropic forecasts of trough displacements at low latitudes, as noted in the study by Dunn [2]. This type of error showed up persistently in the 12-hour barotropic forecasts which are subjectively verified as part of the analysis procedure in A&FB.

Surface developments during this period were complex. The cyclone originally associated with the upper closed Low moved rapidly from the Texas Panhandle to the lower Great Lakes, where it was swept eastward by a short-wave trough in the northern branch of the westerlies. Meanwhile, in response to the slower-moving 500-mb. Low, a new wave formed on the polar front, and by 1200 GMT on the 27th this center was situated in southern Mississippi (fig. 10B).

The barotropic 36-hour 500-mb. forecast (fig. 11A), made at this time and verifying at 0000 GMT on the 29th, showed the closed Low accelerating east-northeastward and becoming absorbed by the westerlies to its north. This represented a potentially important event in that it might well be accompained by rapid surface intensification.

For a preliminary guide as to the future location and strength of the surface Low, several objective prediction

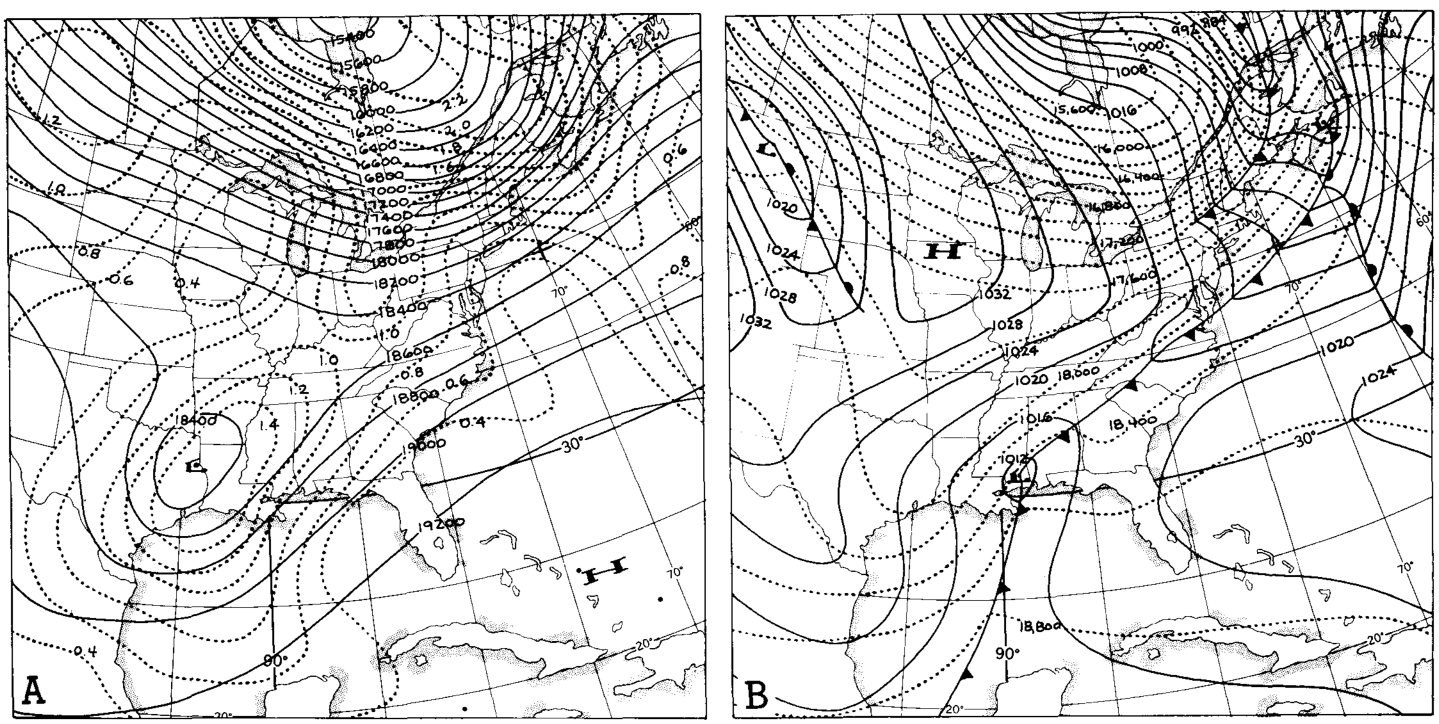


Figure 10.—(A) 500-mb. contour analysis (solid lines) and 500-mb. vorticity analysis (dotted lines with units of 10^{-4} sec. $^{-1}$), 1200 GMT, January 27, 1962. (B) Surface (solid lines) and 1000–500-mb. thickness (dotted lines) analyses, 1200 GMT, January 27, 1962.

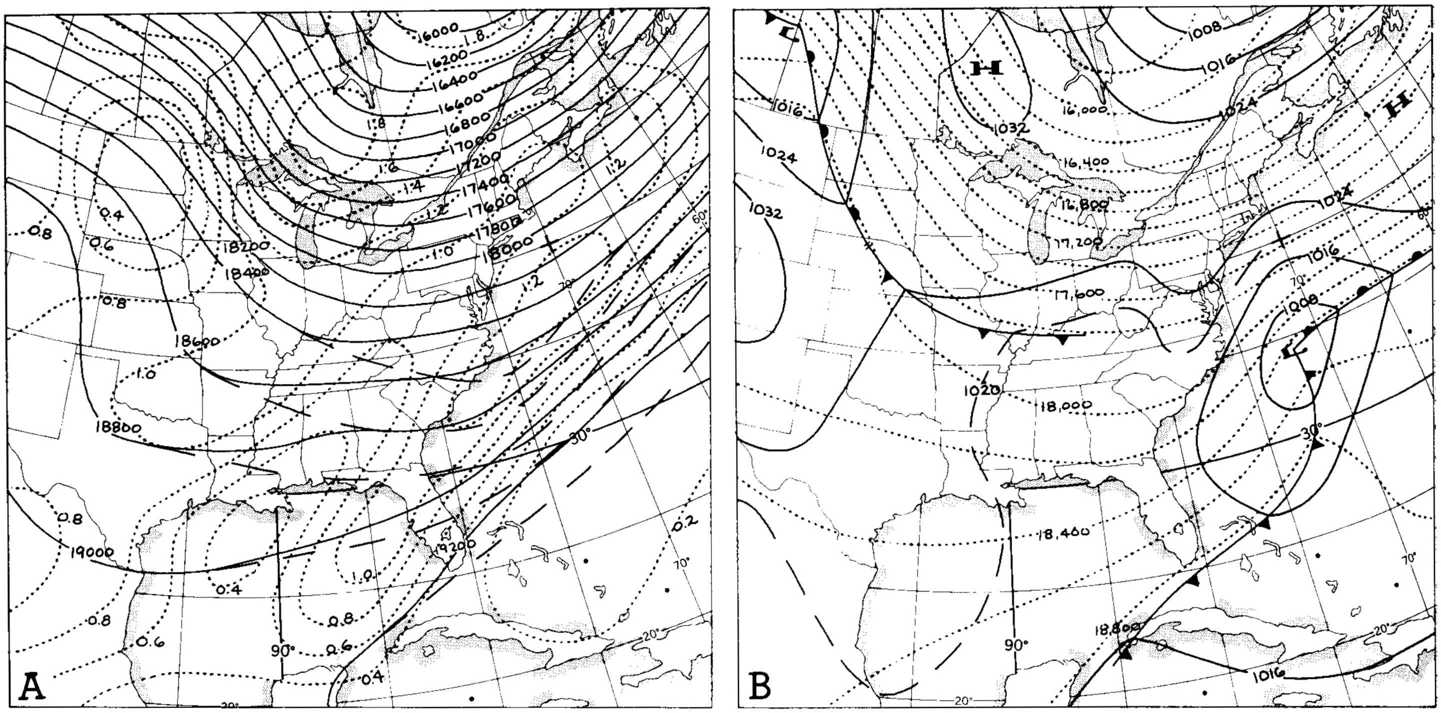


FIGURE 11.—(A) NWP 36-hour barotropic 500-mb. contour forecast (solid lines), A&FB modification (dashed lines), and NWP 36-hour barotropic vorticity forecast (dotted lines with units of 10^{-4} sec.$^{-1}$), verifying time 0000 GMT, January 29, 1962. (B) A&FB 36-hour surface forecast (solid lines) and 1000–500-mb. thickness forecast (dotted lines), verifying time 0000 GMT, January 29, 1962.

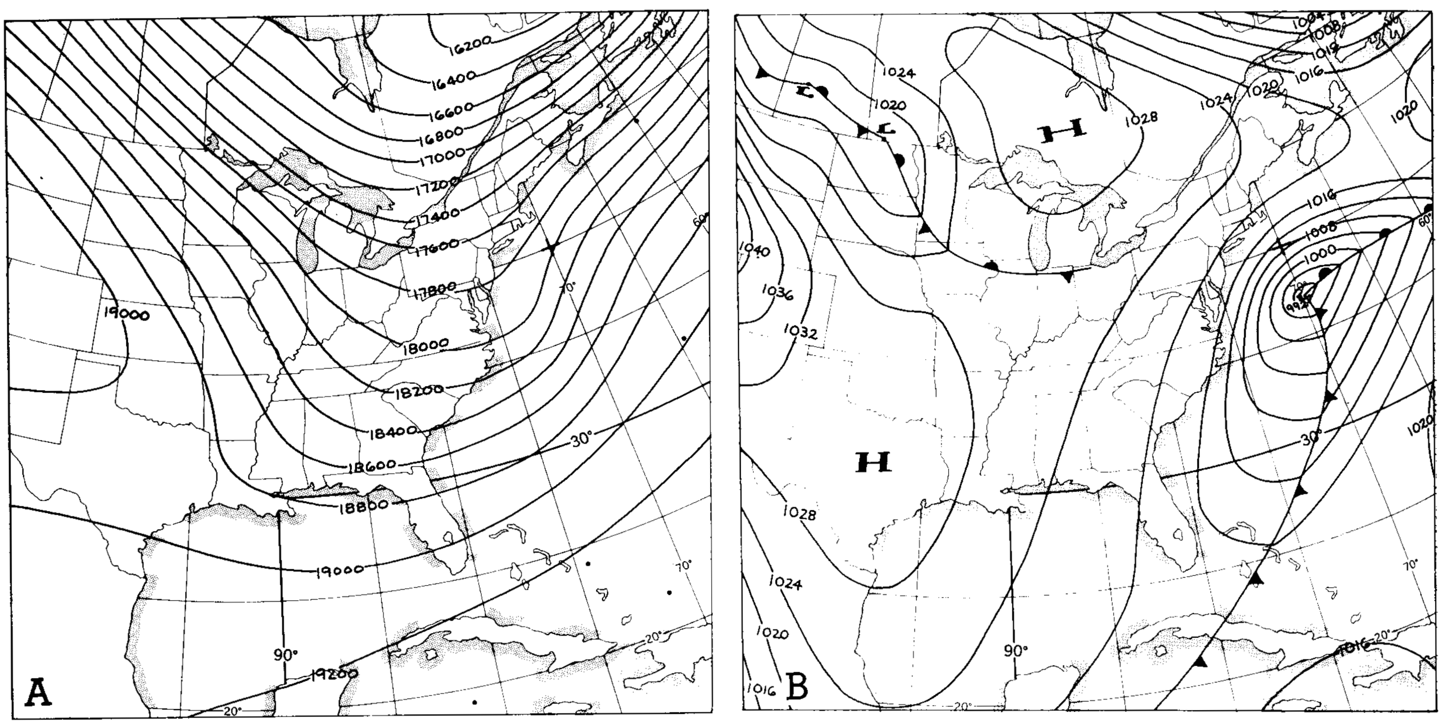


FIGURE 12.—500-mb. contour analysis, 0000 GMT, January 29, 1962. (B) Surface analysis, 0000 GMT, January 29, 1962.

schemes were used. A George computation [5] gave a position at 39° N., 71° W., and a deepening of 5–15 mb. (depending on whether average or maximum intensification was considered to occur). The Hering-Mount method [6] indicated a 36-hour position at 32.5° N., 69° W. An Ostby-Veigas ("Travelers") computation [8] was not attempted since initially the surface wave was outside the area in which this method is designed to work.

The barotropic 36-hour vorticity prognosis (fig.11A) took the concentration of vorticity initially associated with the 500-mb. and surface Lows northeastward to the Cape Hatteras area as an elongated, almost two-celled maximum. The question was then raised as to which "cell" the surface center would ultimately be associated with. A closer look at the initial vorticity maximum (fig. 10A) revealed that it, too, had a somewhat "double-celled" appearance, and that the surface wave initially appeared to be more closely related to the southernmost "cell". A spot 5° of latitude downstream from the forecast southern "cell", was therefore indicated as yet another possible future location for the surface Low.

This was accepted as the final choice for placement since it was felt that of all the methods considered, the barotropic forecast would give the most reliable aid in this case. In support of this decision, a look at Petterssen's charts on wintertime cyclogenesis frequency [9] showed that the chosen location (34° N., 72° W.) was more favorable than areas to the north or south. (Application of Sutcliffe's theories on development [11] [12] was not possible here; the initial 1000–500-mb. thickness over the east coast area (fig. 10B) showed a maximum of gradient far to the north, and no true jet in the southern branch of the thermal wind field could be seen downstream from the surface Low.)

Since the 500-mb. feature associated with this system was forecast to decrease markedly in amplitude, and since the thickness lines downstream were at best straight or even weakly cyclonic, only moderate deepening (11 mb.) was predicted (fig. 11B).

With the barotropic prognosis accepted and the surface center placed accordingly, it remained to decide whether or not to make a correction to the 500-mb. trough for baroclinicity, a technique described by Spiegler [10]. With surface deepening not expected to reach 20 mb. or more, a true Spiegler correction was not indicated, but in view of a certain degree of cold advection or baroclinicity expected to be taking place at the verifying time, some smaller modification of the barotropic forecast still appeared to be in order. Such a correction was made (fig. 11A), in line with A&FB practice [7] as described in section 2 of this article; it will be noted that this change is essentially similar to that described by Spiegler, but of lesser magnitude because of the smaller amount of surface intensification expected.

On the verifying 500-mb. chart (fig. 12A), it can be seen that although the closed Low had opened into the westerlies as forecast, the positive vorticity maximum was farther north than expected. Nonetheless, the 500-mb. error chart (fig. 13) shows that while the barotropic forecast was more than 400 feet too high in the North Carolina area, the modified prognosis reduced this error to somewhat over 200 feet.

The surface map for 0000 GMT on the 29th (fig. 12B) indicates the surface wave verifying about 200 miles northeast of the forecast position, and some 10 mb. deeper than expected. With regard to local forecast problems, this additional intensification and more northerly track was particularly critical, since a band of heavy snow fell to the north of the track and some areas along the middle Atlantic coast received their heaviest snowfall of the winter.

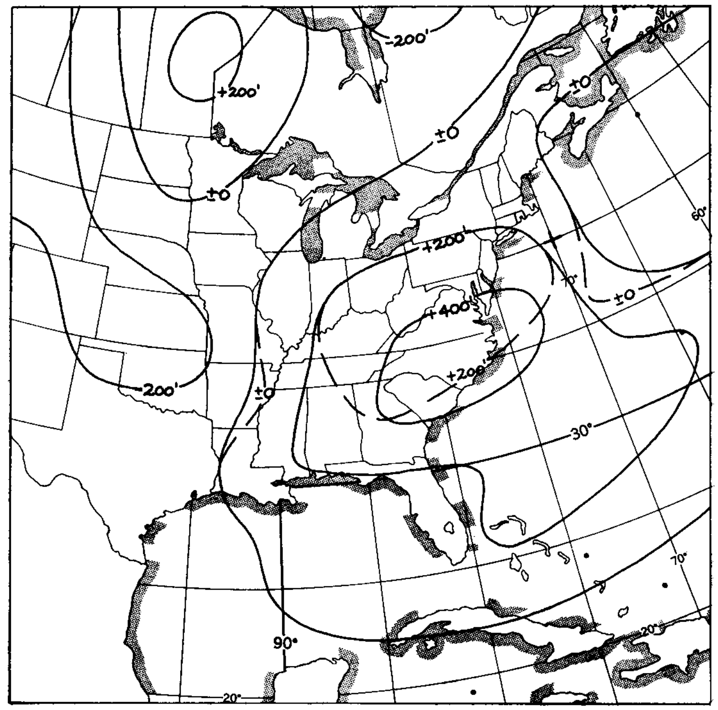


Figure 13.—Error of the NWP 36-hour barotropic 500-mb. contour forecast (solid lines) and A&FB modification (dashed lines) verifying at 0000 GMT, January 29, 1962.

In retrospect, it appears possible that the additional heat source represented by the Gulf Stream contributed to a degree of deepening not adequately predicted by any of the objective systems. At first glance, the George computation appears to have given the best clue as to the more northerly verifying position of the storm, but it is also true that if the forecaster had chosen a spot 5° downstream from the middle of the elongated 36-hour vorticity maximum (rather than the middle of the southern "cell"), a better forecast would have resulted. Thus, it is evident that even with the use of a number of objective aids including computer-produced prognoses, there is still ample opportunity for the forecaster to use his skill in making the proper subjective interpretations of these aids.

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